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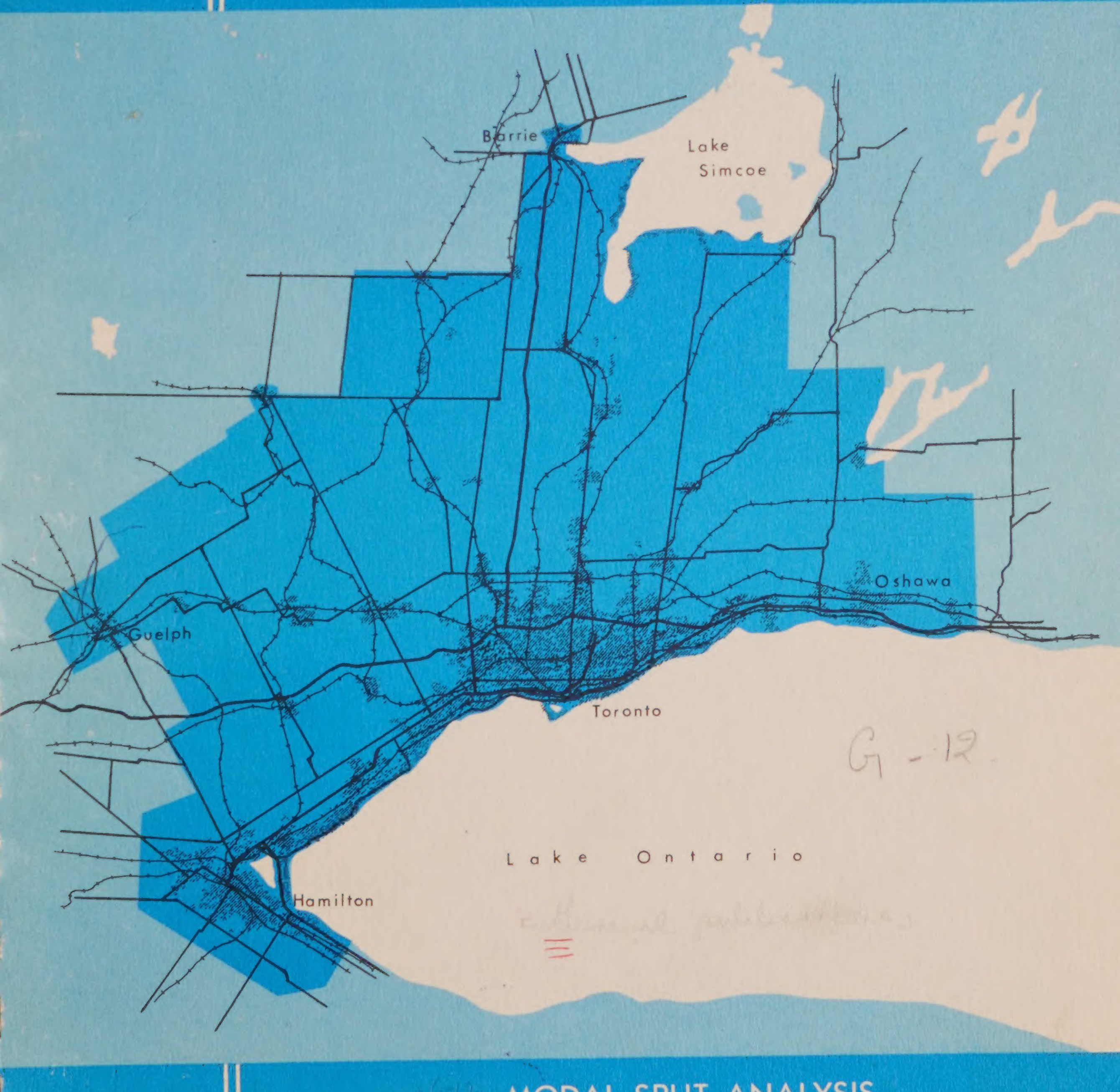
METROPOLITAN TORONTO AND REGION TRANSPORTATION STUDY



DECEMBER 1965

MODAL SPLIT ANALYSIS
for Traffic Prediction Model

PREPARED FOR METROPOLITAN TORONTO AND REGION TRANSPORTATION STUDY BY TRAFFIC RESEARCH CORPORATION

TRAFFIC RESEARCH CORPORATION LIMITED

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May 31, 1965.

Mr. P. E. Wade, P. Eng.,
Study Director,
Metropolitan Toronto and Region
Transportation Study,
10 St. Mary Street, 3rd Floor,
TORONTO, Ontario.

Dear Mr. Wade:

We are pleased to submit herewith our report on the analysis of the Three-Way Modal Split for Metropolitan Toronto and Region. The analysis comprised an investigation of the relationships between the number of persons choosing the auto, transit or rail-commuter mode, and such factors as time, cost and convenience of travel by each mode. Specifically the analysis was devised to develop the relationships applicable to commuter travel.

The work carried out during the course of this project was in accordance with the Memorandum of Agreement dated December 1, 1964. In particular this report describes the following:

1. Summary of Research
2. Concept of Modal Split Technique
3. Data Sources
4. Results of Three-Way Modal Split Research

This project comprises an essential phase of the MTARTS Planning Process. The findings will be critical inputs for the prediction of the ridership on proposed or planned commuter facilities in the Region.

The work described in this report represents an extension of the analysis conducted on behalf of the Metropolitan Toronto Planning Board in their development of a Traffic Prediction Model. The 1964 Home Interview Survey which was conducted jointly by the Metropolitan Toronto and Region Transportation Study and the Metropolitan Toronto Planning Board, was the basic source of data applied in the analysis.

Continued ..../

Due to the absence of extensive ridership on rail commuter facilities, it was decided to supplement this analysis with data from another typical North American city. The City of Philadelphia in many ways (i. e. socio-economic) is similar to Metropolitan Toronto and Region, and furthermore supports an extensive rail-commuter operation. Special arrangements were made to apply data of the 1960 Home Interview Survey for the City of Philadelphia in the analysis described in this report.

We are grateful to you, your staff, and to other cooperating agencies, especially the Metropolitan Toronto Planning Board and the Penn-Jersey Transportation Study, for the help received in carrying out this interesting and important project. We feel the results presented in this report represent a significant contribution to the art of travel movement forecasting.

Yours very truly,

H Golube

T/HGvC:db
Encl.

H. G. von Cube,
Vice-President.

METROPOLITAN TORONTO AND REGION
TRANSPORTATION STUDY

THE

THREE-WAY MODAL SPLIT ANALYSIS

Prepared

for the

METROPOLITAN TORONTO AND REGION
TRANSPORTATION STUDY

by

TRAFFIC RESEARCH CORPORATION LTD.

APRIL, 1965

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DESCRIPTION OF M.T.A.R.T.S. THREE-WAY MODAL SPLIT RESEARCH

1. INTRODUCTION

People who travel medium to long distances frequently have the choice of travelling via three main alternative modes of travel. These are as follows:

1. automobile (driver or passengers);
2. bus, streetcar, and/or subway;
3. commuter railway and/or commuter bus.

On the other hand, people who travel short to medium distances, will, as a rule, only travel by the two modes:

1. automobile;
2. bus, streetcar and/or subway

Studies conducted on behalf of the Metropolitan Toronto Planning Board have dealt primarily with the study of considerations affecting people's choice of the automobile versus transit mode.[1] In particular, this research involved short to medium distance trips. However, in a study region as large as the MTARTS Area,

1. "An Analysis of Some Travel Trends Between 1956 and 1964 based on Home Interview Surveys", prepared for the Metropolitan Toronto Planning Board by the Traffic Research Corporation Limited, March, 1965.

there are a considerable number of trips occurring with trip lengths exceeding 20 miles. As a result, considerable attention must be directed towards estimating the modal split of long distance travellers as well as medium and short distance travellers. Therefore, a Three-Way Modal Split technique must be utilized in the Regional Traffic Prediction Model (TPM) for the forecast of automobile, bus, streetcar, subway, transit and rail commuter ridership. The Three-Way Modal Split Analysis is required to provide the necessary travel relationships for the Traffic Prediction Model.

The Model accommodates the Three-Way Modal Split in the following manner:

(a) Total O-D person trip interchange is divided into automobile traffic and public transportation traffic using time ratio diversion curves. The travel advantages of public transportation are based on a weighted average of the characteristics of bus, streetcar, subway and rail commuter travel (weights are determined according to probable assignment to each type of transit facility), and are compared with the travel advantages of the automobile (see Chapter 3).

(b) Trips by Public Transportation are further divided into bus, streetcar, subway and railroad ridership in accordance with the time and cost advantages of each.

Hence, the TPM Modal Split Methodology utilizes a Three-Way technique (i.e. automobile, local transit and commuter rail or bus) as it permits the further breakdown of public transportation ridership

according to the type of facility.

2. SUMMARY OF RESEARCH

The data sources for the MTARTS Region (1964) and the City of Philadelphia (1960) were utilized to establish the necessary relationships for the Modal Split technique.

In summary, the work conducted was as follows:

2.1 Selection of Study Zones

Appropriate Study Zones were delineated for the MTARTS Region and the Philadelphia Area, so as to have uniform socio-economic travel characteristics (see Maps 1 and 1a for MTARTS Region). MTARTS and Philadelphia Study Zones were made consistent with the basic traffic zones of the travel surveys.

2.2.1 Summary of Travel Characteristics

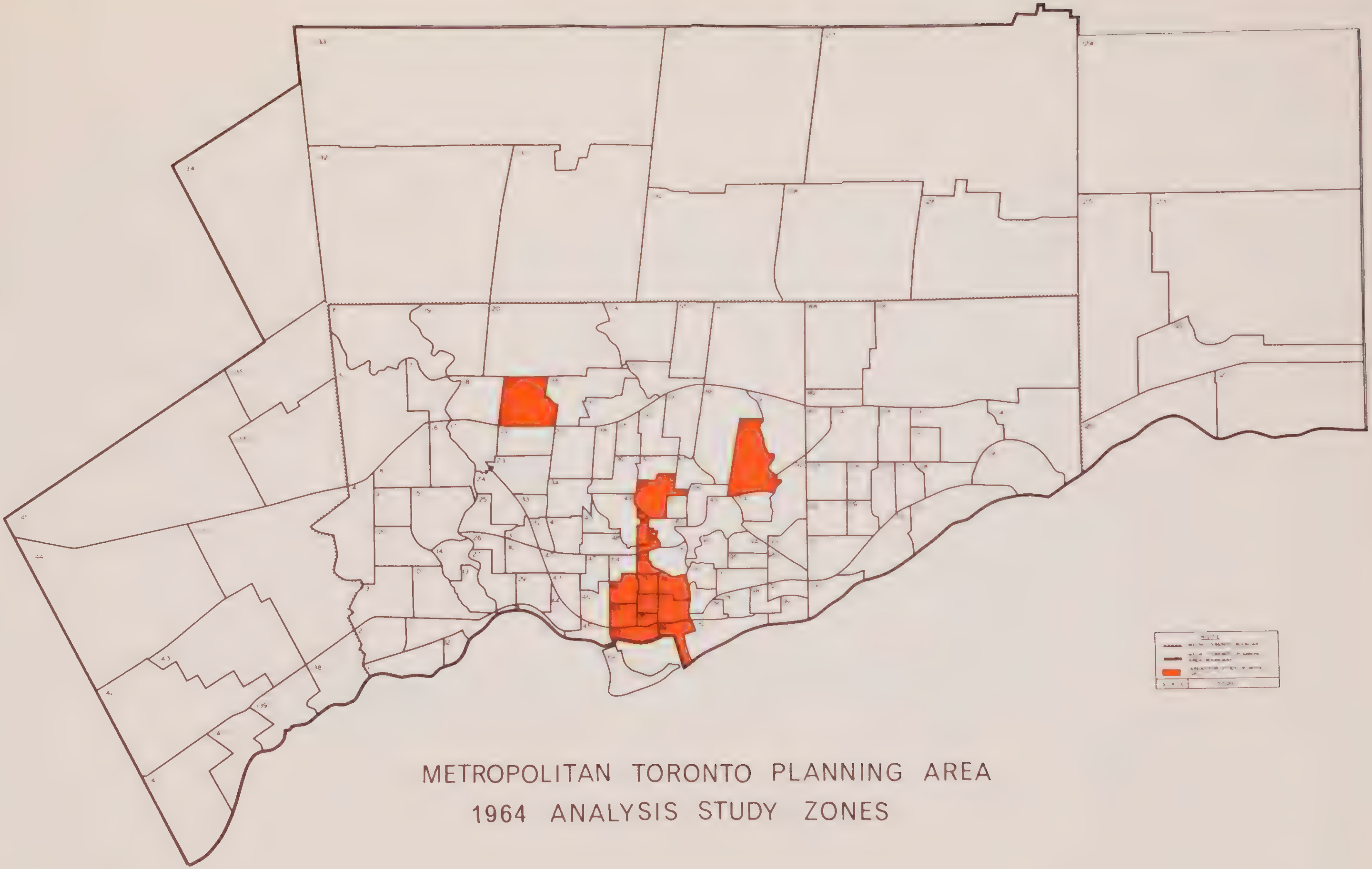
The following data from the Home Interview Survey for the MTARTS and Philadelphia Study Regions were summarized from all zones to CBD zones for home based work trips in AM peak period (2 hours) and for home based non-work trips in off peak period (20 hours):

(a) automobile, railroad and other transit ridership;

(b) door-to-door reported travel time by each mode;

(c) parking cost;

(d) economic status.



METROPOLITAN TORONTO PLANNING AREA
1964 ANALYSIS STUDY ZONES

MAP I

METRO TORONTO & REGION TRANSPORTATION STUDY
1964 ANALYSIS STUDY ZONES

MAP 1a

The average income per worker was derived from survey and/or census information and was used at the measure of socio-economic status.

2.2.2 Data From Other Sources

Summaries of other travel characteristics were prepared from other data sources as follows:

(a) Origin and destination travel costs by mode, i.e. fares, motor vehicle operating costs, etc.

(b) Automobile, railroad and public transit excess times, i.e. waits, walks, transfers, other delays, etc.

The details are presented in Chapter 4 for MTARTS and Philadelphia data respectively.

2.2.3 Research on Transit and Automobile Ridership

(a) Captive Ridership

The MTARTS and Philadelphia data sources described the characteristics of the automobile rider, the transit rider and the railroad rider. The possession of a driver's licence was noted; household car ownership was specified; and reasons for choice of mode were reported in the case of the MTARTS Survey. A captive transit rider is a person who belongs to a household which does not own a car; or is a person who does not possess a driver's licence. In the case of the MTARTS work trip data, automobile drivers would report when the car was necessary to do one's

work (i. e. auto captives). Summaries of the percentage of traffic designated as captive transit and captive automobile ridership were prepared for each O-D pair, origin zone and destination zone.

Captive trip summaries were prepared for the following trip purposes and time periods:

(a) Captive transit rail ridership (MTARTS and Philadelphia)

- Home based work trips to CBD during AM peak (CBD, i. e. Central Business District)

- Home based non-work, non-school trips to CBD in off-peak periods.

(b) Captive automobile ridership (MTARTS only)

- Home based work trips to CBD during AM peak.

The overall rates of captive public transportation ridership are as follows:

REGION	WORK TRAVEL	NON WORK TRAVEL
MTARTS	56%	78%
PHILADELPHIA	49%	78%

The level of captive ridership in the two regions is similar. However, the captive ridership for work and non-work travel differ significantly.

MODE	WORK TRAVEL	NON WORK TRAVEL
RAILROAD	14%	55%
OTHER TRANSIT	57%	80%

The overall rates of captive railroad versus other transit ridership differ most significantly for the Philadelphia Region as shown:

The rate of captive automobile ridership in the MTARTS Region is lower than the captive transit ridership but is considered high at a rate of 38%.

Due to the similarity in the level of captive ridership, the comparison of MTARTS and Philadelphia diversion curves was considered possible. Because of the problems associated with projecting captive ridership for future years, the uncertainty regarding the captive or choice status of an automobile passenger, and the absence of data on automobile captives for the Philadelphia area, modal split relationships were developed for total ridership and not separately for captive and non-captive travellers.

(b) Total Ridership

Summaries of total ridership were prepared as follows:

(a) Total transit and rail ridership (MTARTS, MTPB and Philadelphia)

- Home based work trips to CBD during AM peak

- Home based non-work, non-school trips to CBD in off-peak periods

- Home based school trips to CBD during AM peak (MTARTS only).

(b) Rail ridership (MTARTS, MTPB and Philadelphia)

- Home based work trips to CBD during AM peak

(c) Total transit ridership excluding rail (MTARTS, MTPB and Philadelphia)

- Home based work trips to CBD during AM peak.

Note: Ridership was expressed as absolute trips and as the proportional share of total trips (percentage).

2.3 <u>MTARTS and Philadelphia Modal Split Relationships for Public Transit versus Automobile Ridership</u>

Travel time ratios, cost ratios, service ratios and average worker income were calculated for each origin and CBD destination interchange. Using these factors and the summarized ridership data of Step 2.2.3(b) (summaries (a), (b) and (c)), time ratio diversion curves were developed for MTARTS and Philadelphia Regions. The following sets of relationships were established:

(a) MTARTS Relationships for:

- Home based work trips to CBD in AM peak (combined, rail and transit separately)

- Home based non-work, non-school trips to CBD in off-peak periods (combined only).

Note: Home based school trips to CBD in AM peak were not established, due to insufficient data.

(b) Philadelphia Relationships for:

- Home based work trips to CBD in AM peak (combined, rail and transit separately)

- Home based non-work, non-school trips to CBD in off-peak periods (combined only).

The relationships were established for combined public transport versus auto, railroad versus auto and other transit versus auto ridership. All relationships were stratified according to worker income, level of cost ratio, and level of service ratio. (See Chapter 4).

Investigation of the survey data for the MTARTS Region has demonstrated that 27 stratification levels explain adequately the differences in the ridership habits of the public. The data stratifications are as follows:

(a) Three levels of Worker income:

ec.	1.	0 to $3190
	2.	$3190 to $4840
	3.	$4840 and over

(b) Three levels of Cost Ratio:

cr.	1.	0.0 to 0.5
	2.	0.5 to 1.5
	3.	1.5 and over

(c) Three levels of Service Ratio:

sr.	1.	0. 0 to 1. 5
	2.	1. 5 to 3. 5
	3.	3. 5 and over

Combined railroad and transit Modal Split Relationships were determined from the data of the MTARTS and Philadelphia Regions. A comparison of these relationsips demonstrated significant differences in the levels of ridership in MTARTS and Philadelphia Regions. The ridership of public transportation in Philadelphia is consistently higher. No explanation is presented here of the reasons for the differences, however, a few unsubstantiated conjectures are mentioned in Chapter 5.

A final set of relationships has been established from the basic findings presented in Chapter 5. Since it is recognized that the Survey data for the MTARTS Region does not provide information on the ridership of the public when transit is very speedy (time ratios of less than 0. 5) or when transit is very slow (time ratios greater than 3. 0) the basic Modal Split Relationships must be extrapolated beyond this range. The following extrapolation procedure was adopted:

(a) For time ratios of zero (0), assume that transit ridership is 85 percent for work trips (i. e. minimum of 15 percent captive auto ridership was observed), and assume otherwise a straight line (linear) extrapolation for non-work trips.

(b) For time ratios of five (5) and over, assume that transit ridership is zero percent for all trips irregardless of purpose.

The recommended set of relationships are presented in Figures 1 and 2 for Work and Non-Work Travel respectively. These relationships display consistent levels of ridership. They are extrapolated in accordance with the above procedures and otherwise estimated, when data was missing, based on experience.

In the application of these relationships, it is recommended that a fourth service ratio category be employed. This is to ensure that transit ridership can be set to zero for instances of no service, or otherwise be set to some predetermined minimum level of ridership.

All graphic materials which were prepared to display the basic relationships and supported by data summaries, have been bound into an appendix. This appendix was submitted previously to the Metropolitan Toronto and Region Transportation Study on March 19, 1965.

2.4 <u>Diversion Relationships of Railroad or Other Transit Versus Automobile Ridership</u>

For equal levels of worker income, cost ratio and service ratio a comparison of the railroad and other transit time ratio diversion curves was conducted. Differences were

reviewed for degree of significance. The analysis was conducted primarily with the Philadelphia data. As well, some study was given to the MTARTS data. Details are reported in Chapter 5.

The interpretation of the comparative evaluation of railroad and other transit Modal Split relationships is as follows:

(a) Differences between railroad and transit ridership in Philadelphia are quite significant. These differences appear to be attributable to remarkable differences in rates of captive ridership on railroad versus transit (14% versus 57%).

(b) Railroad and transit ridership in MTARTS Region is similar.

(c) Provided the tariff of competitive railroad and other transit services are equivalent, the captive ridership of railroad and transit facilities appears similar. Accordingly, no significant differences between railroad and transit ridership is expected. (see Chapter 5).

In conclusion, we recommend the application of the Modal Split Relationships shown in Figures 1 and 2, for the estimation of total railroad and transit ridership . Separate estimates of railroad and transit ridership can be determined by the procedure recommended in the next Section 2. 5.

2. 5 Railroad Versus Transit Diversion Relationships

Using the summaries of data concerning railroad and other transit ridership, the parameters of the railroad versus

RECOMMENDED MODAL SPLIT RELATIONSHIPS
OF WORK TRAVEL IN M.T.A.R.T.S REGION

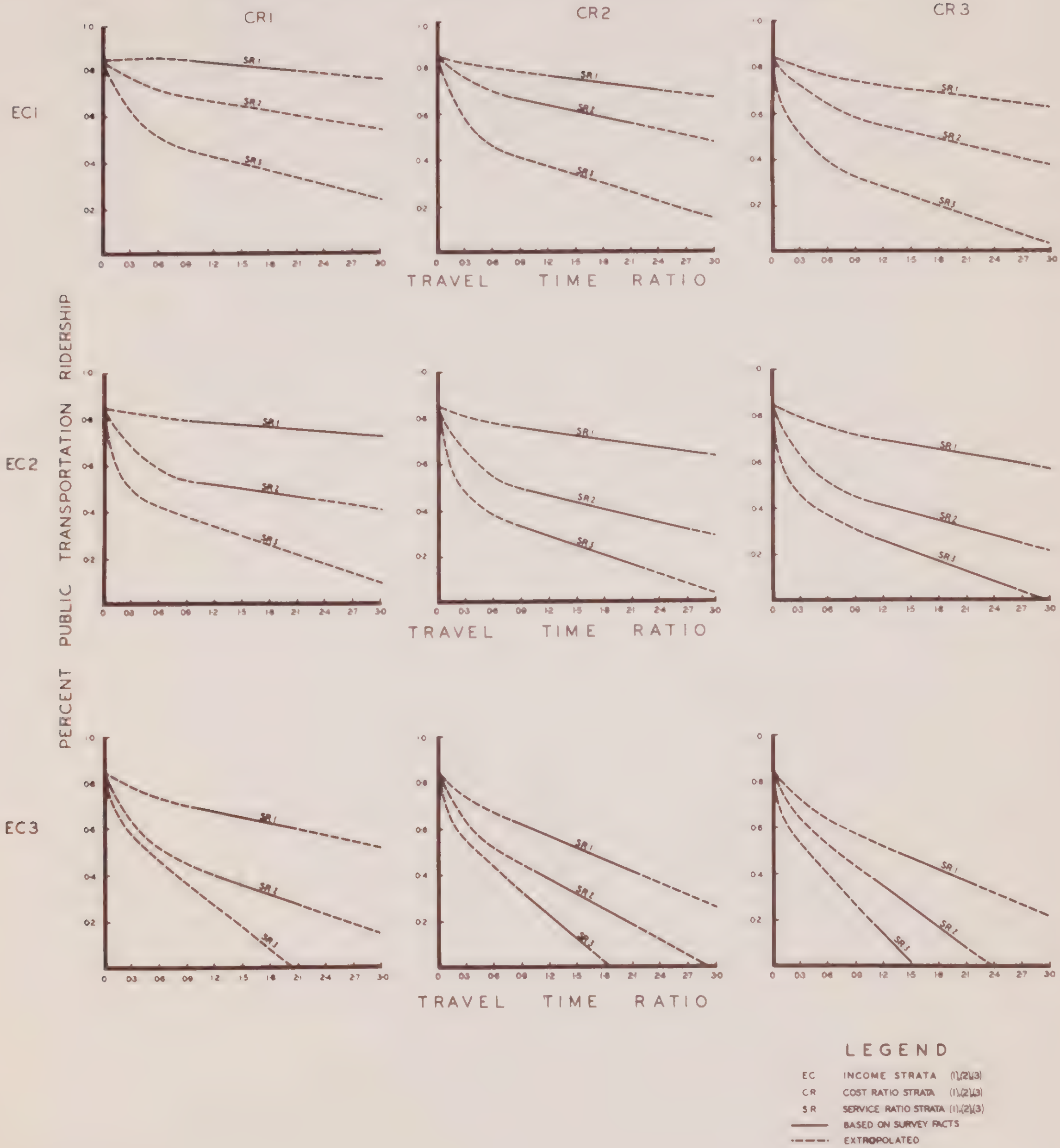


FIG. 1

RECOMMENDED MODAL SPLIT RELATIONSHIPS OF NON-WORK TRAVEL IN MTARTS REGION

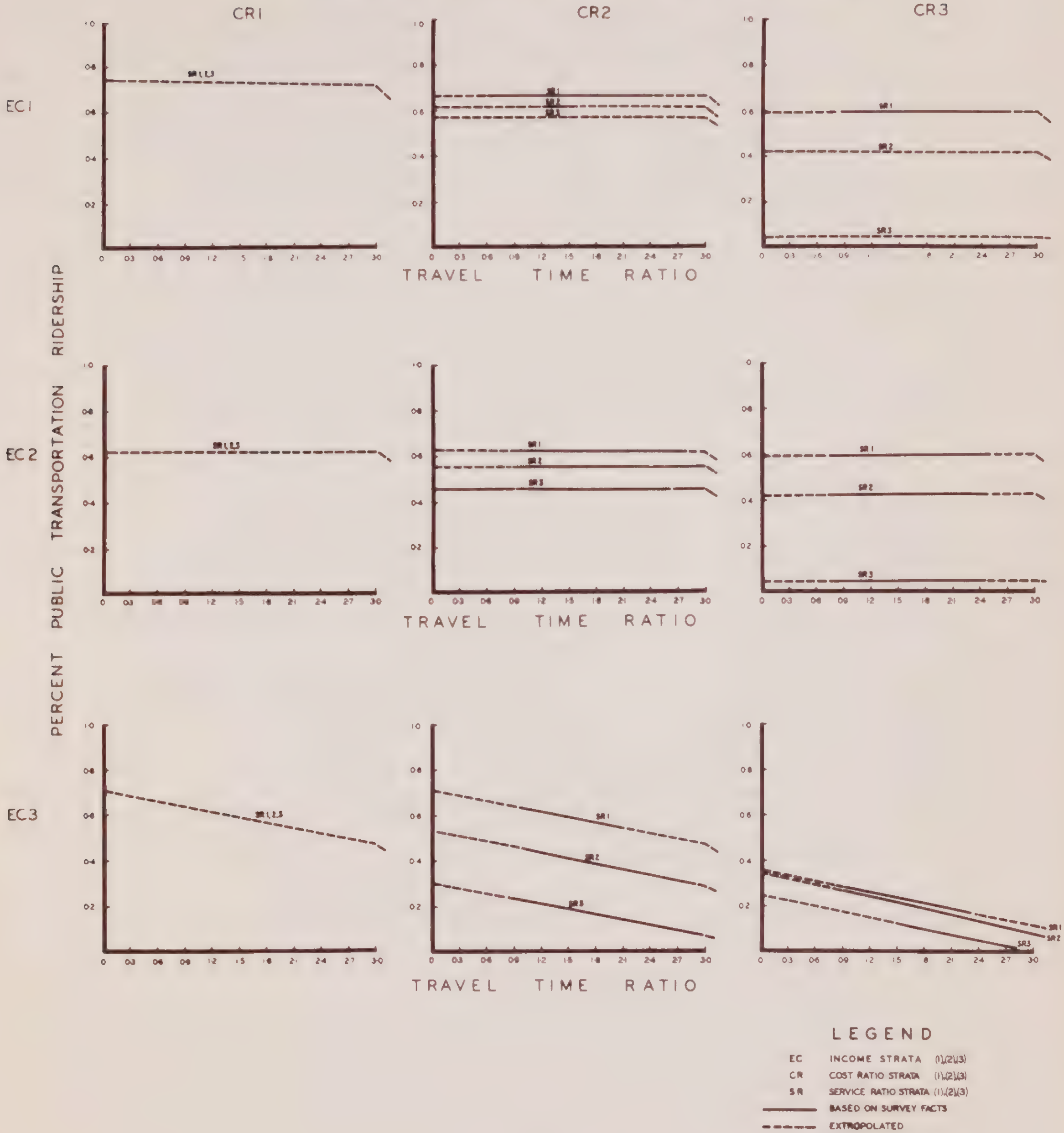


FIG. 2

transit diversion relationships were established.

The Model carries out the diversion of public transport ridership into railroad and other transit by the following formula: (see Figure-3).

$$\text{Railroad share of public transport} = \frac{(Tr + a\ Cr)^b}{(Tr + a\ Cr)^b + (Tt + a\ Ct)^b}$$

$$\text{Other transit share of public transport} = 1.00 - \text{railroad share}$$

where: Tr = travel time by railroad

Tt = travel time by other transit

Cr = travel cost by railroad

Ct = travel cost by other transit

Consequently, it was the purpose of this analysis to derive the parameters, "a and b" of the above time/cost diversion relationship for travel route assignment.

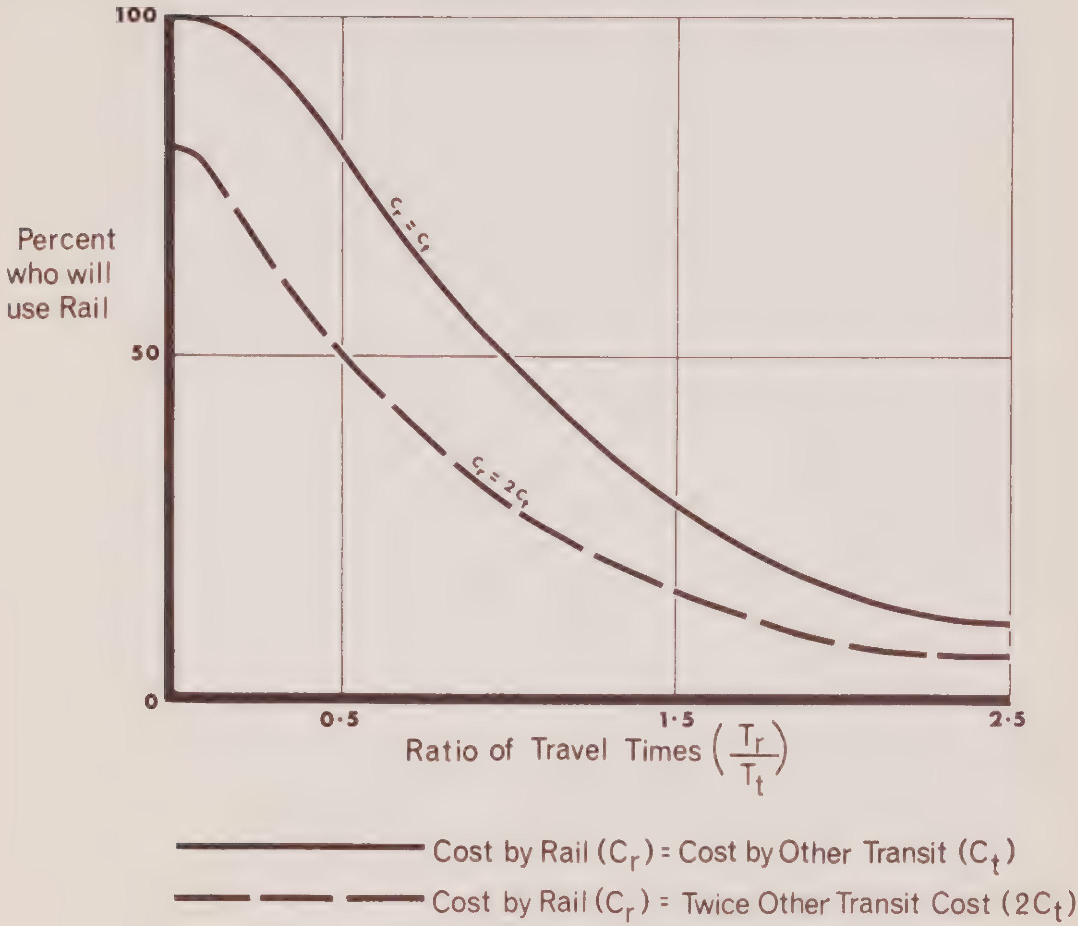
Values of the parameters "a and b" associated with the diversion curve formula described were obtained by non-linear and step-wise regression analysis. The parameters were obtained by analysis of base data for Philadelphia. Analysis of MTARTS data did not contradict the findings.

The following parameter values are recommended for application with the Traffic Prediction Model.

a = + 0.75

b = - 3.4

ASSIGNMENT CURVE SHOWING PERCENT OF TRANSIT RIDERSHIP WHO USE RAIL WHEN THE CHOICE IS BETWEEN RAIL & OTHER TRANSIT



$$\text{Railroad share of Public Transport} = \frac{(T_r + aC_r)^b}{(T_r + aC_r)^b + (T_t + aC_t)^b}$$

FIG. 3

These values apply when "a" is associated with travel cost in cents and "b" is associated with travel time in minutes.

2.6 Comparison of MTARTS and Philadelphia Relationships

In the final step of the analysis of Three-Way Modal Split, a comparison of the MTARTS and Philadelphia relationships was conducted for each level of worker income, cost ratio and service ratio. In cases where comparable data were available, differences were scrutinized for levels of significance. In instances of certain data stratas for high worker income and low cost ratio, little or no MTARTS data were available. Accordingly, the Philadelphia relationships were recognized as having an important role in the estimation of transit usage for the MTARTS population in future years.

3. THE CONCEPT OF MODAL SPLIT TECHNIQUE

The total number of people moving during a certain time period from an origin zone (O) to a destination zone (D), may be thought of as the total travel market existing between the O and D in question. The various modes of travel available for moving from the O to the D are competing for a share of this market, and each will win a portion of it, depending on its competitive position with the others. In this analysis the comparative advantages and disadvantages of each of the two major types of travel mode (public transit and private automobile) are measured by the time, cost and convenience criteria. Other criteria such as economic status and trip purpose, may be thought of as market characteristics which affect user reaction to the first three criteria.

In order to isolate the effects of the five determinants on market reaction (i.e. relative usage of transit and autos), it is necessary first to calculate the value of relative travel time, relative travel cost, and relative service, describing the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It is also necessary to determine the average economic status (income category) of travellers proceeding from the O to the D. Next, the percentage

of travellers proceeding from the O to the D using public transit and private automobile is determined for each trip purpose and is related to each of the other four determinant factors.

If these five factors explain completely the modal choice process, one would expect that all O-D pairs with identical values of time, cost and service ratios and user income level would each display the same percentage of work trips made via public transit. The factors should produce the same percentage of non-work trips made via public transit for O-D pairs with identical values of the factors. However, this percentage would in general be different from the percentage of work trips made via public transit.

THE MODAL SPLIT TECHNIQUES

The modal split technique is basically a diversion curve procedure. The diversion curves demonstrate in quantitative form how the propensity to travel by public transit as opposed to travel by private automobile, is related to the five basic determinant factors. The five factors are the following:

1. The ratio of door-to-door travel time via public transit to the door-to-door travel time via private automobile;

2. The ratio of out-of-pocket cost via public transit to the out-of-pocket cost via private automobile;

3. The ratio of excess travel time via public transit to excess travel time via private automobile. This ratio is a measure of the relative level of travel service and convenience;

4. Economic status of trip maker;

5. Trip purpose.

The factors are demonstrated below in equation form:

1. Travel time ratio $= \dfrac{TQ + WKQO + WKQD + WQ + TR}{TV + WKVO + WKVD + WVO + WVD}$

where: TQ = time en route on transit vehicle;

WKQO = time spent walking from trip origin to transit vehicle;

WKQD = time spent walking from transit vehicle to destination;

WQ = time spent waiting for transit vehicle;

TR = time spent transferring between transit vehicles;

TV = time en route in private automobile;

WKVO = time spent walking between trip origin and parking space;

WKVD = time spent walking between parking space and trip destination;

WVO = parking delay time at trip origin;

WVD = parking delay time at trip destination.

2. Cost ratio = $\dfrac{FR}{[CF + CO + [(PKO + PKD)/2]/NPPV]}$

where: FR = transit fare;

CF = gasoline cost; $\left(\dfrac{\text{gallons}}{\text{mile}} \times \text{distance} \times \dfrac{\text{cost}}{\text{gallon}}\right)$

CO = oil change and lubrication cost; $\left(\dfrac{\text{cost of oil change}}{\text{mile}} \times \text{distance}\right)$

PKO = parking cost at origin of trip;

PKD = parking cost at destination of trip;

NPPV = number of passengers per vehicle.

3. Service ratio = $\dfrac{WKQO + WKQD + WQ + TR}{WKVO + WKVD + WVO + WVD}$

4. Economic Status expressed in median income per worker or by other suitable measures.

5. Trip purpose, individually or in combination. Different sets of diversion curves are used for each trip purpose.

There can be up to 80 diversion curves for each trip purpose. The diversion curves demonstrate the relationships between transit usage and the travel time ratios for not more than 4 levels of cost ratio, nor more than 4 levels of service ratio and for not more than 5 levels of economic status (4 x 4 x 5 = 80).

The five factors were chosen as a result of multiple regression analysis in which the effects of a large number of variables on

propensity to use public transit as opposed to a private automobile were studied. The relationships are based not on interviews asking people how they would like to travel, but on an analysis of how people have actually travelled when faced with time, cost and convenience of competing modes of travel. Details of the development of the forecasting techniques are reported in the paper entitled "Development of Model for Forecasting Travel Mode Choice in Urban Areas" by D. M. Hill and H. G. von Cube, presented to the Highway Research Board, January, 1963.

THE MODAL SPLIT PROGRAM

The Modal Split Relationships described above are used to forecast the percentage of total trips, by purpose, proceeding from an origin to a destination, which will be made by public transit. In order to employ the relationships for the above application, reliable estimates of travel time, travel costs, excess times and the average economic status of the trip maker are required. This information is translated into the four modal split indices, i.e. time ratio, cost ratio, service ratio, and socio-economic status. When these indices have been calculated, the probable modal split for each O-D pair is determined by selecting the appropriate curves, and by interpolating among these curves.

Multiplying the percentage transit usage by the total person movements from each O to each D, produces an estimate of the number of O-D transit passenger trips. The estimate of automobile passenger trips is the difference between total person trips and transit trips. The number of auto driver trips is obtained by dividing the auto passenger trips by the expected car occupancy. The above procedures are carried out separately for each trip purpose of interest.

While the methodology of the Modal Split is conceptually quite simple, a detailed description of it is, of necessity, quite lengthy and consequently is not reported here.

4. DATA SOURCES

SURVEY DATA OF THE METROPOLITAN TORONTO AND REGION TRANSPORTATION STUDY

The basic Home Interview Survey data used in this research study for Metropolitan Toronto and Region has been described in the report:

> "1964 Home Interview Survey"
> Report on Methods and Results,
> prepared for Metropolitan
> Toronto and Region Transportation Study, March, 1965.

Appropriate Study zones were delineated for purposes of summarizing modal split data. The 914 MTARTS data collection zones were combined into approximately 174 modal split analysis zones. Exactly 145 of the study zones were delineated for the MTPB Planning Area, and the remainder were assigned to the outside region with adequate detail along the "Lakeshore Corridor", between Hamilton and Toronto (See Maps 1 and 1a). The basic data zones were combined into Modal Split study zones so that the following requirements were satisfied:

(a) uniform distribution of income throughout study zone.

(b) accurate representation of transit or railway service with uniform service throughout zone

(c) zonal areas did not exceed 2 to 3 square miles except for sparsely developed areas

Fifteen of the study zones were specified as CBD zones i. e. downtown and uptown zones #50, 61, 62, 63, 65, 66, 67, 69, 70, 71, 72, 73, 74 which were adjacent to the Yonge Street Subway, and two suburban zones with high employment #21 and 85.

4.1.1 Home Interview Survey Data

The survey reported trips for eight travel modes as follows:

Mode 1	auto driver
Mode 2	auto or truck passenger
Mode 3	taxi passenger
Mode 4	public transit
Mode 5	railway
Mode 6	school bus
Mode 7	other
Mode 8	walk between home and work

Trips involving transfers between different modes were linked and assigned the mode of highest priority.

Mode priorities were specified as follows:

(a) railway

(b) public transit

(c) school bus

(d) auto or truck passenger, auto driver

For the purpose of this research study, the following mode combinations were considered:

(a) private automobile, comprising modes 1, 2 and 3

(b) railway, comprising mode 5

(c) public transit, comprising modes 4 and 6

Note: Trips of modes 7 and 8 were omitted from the analysis, as not pertinent.

In addition to mode of travel, the following summaries of travel facts were prepared from the survey:

4.1.1.1 Door-to-Door Travel Time by mode

Departure and arrival times were reported for each trip. The difference between these reported times, was applied as a measure of the door-to-door travel time for each selected origin and (CBD) destination zone. Unusual times between zones were adjusted to agree with travel times reported for adjacent O-D interchanges. Times not reported in the survey, due to absence of trips by a particular mode, were obtained by substituting known times from adjacent zones.

4.1.1.2 Parking Cost Per Vehicle

The type of parking used (i.e. free, pay or street metered), the parking fee paid and the automobile occupancy were recorded for each automobile driver trip. These data were summarized and

the average parking costs and car occupancy were calculated. The average parking costs per vehicle are shown below in Table 1 for each trip purpose at destination. zones.

Table 1

AVERAGE COST OF PARKING

Zone (see map)	Parking Cost Work	Non Work
21	0¢	0¢
50	8¢	3¢
61	10¢	5¢
62	14¢	11¢
63	21¢	15¢
65	70¢	7¢
66	28¢	6¢
67	13¢	13¢
69	5¢	0¢
70	104¢	22¢
71	23¢	0¢
72	72¢	31¢
73	52¢	29¢
74	8¢	8¢
85	0¢	0¢

Automobile occupancy was reported to be on the average of 1.4 persons per car for all purposes.

4.1.1.3 Travel Service

Waits and walks experienced in transit travel are referred to as transit excess times, and are used as a measure of convenience of public transportation travel.

The walking times at trip origin and destination were reported

for each person trip. An average of 3 minutes walk was reported for the 13 CBD downtown and uptown designated zones (transit and railway trips made to work and non-work purposes). Otherwise a figure of 5 to 6 minutes was reported for zones 21 and 85. Other zones in the central part of the Metropolitan Toronto were shown to have an average 3 minute walk to and from transit. Zones in suburban areas were reported to have 5 to 6 minute walk times on the average to and from transit.

Walking times to parking facilities plus the delay at the facilities are taken as a measure of convenience of motor vehicle travel. Such times are generally negligible at the home end of the trip but are often substantial at the destination end of the work trip. Walking times to and from parking lots were reported to vary between 2 and 4 minutes. A 1 to 2 minute parking delay time was estimated and added to this figure. Based on this analysis for the 13 uptown and downtown CBD zones, a figure of 6 minutes was applied. The two suburban zones (21 and 85) were assigned a figure of 3 minute walking time.

4.1.1.4 Economic Status

Total household income was reported for each survey household. This figure was divided by the number of workers in each household to provide an income per worker figure, which was used as the single measure of socio-economic status for each zone.

4.1.1.5 Data Tabulations from Home Interview Survey

Zonal averages were obtained by summarizing and averaging individual household information for each study zone. A special summary program was prepared to summarize the following data.

For selected origin and destination interchanges, the number of expanded trips by the following trip purposes was tabulated:

- Home to Work in CBD
- Home to Business, Commercial, Social, Recreation in CBD
- Home to School in CBD

In addition, the following data were also tabulated for each study zone interchange and for each of the above trip purpose categories for AM peak and off-peak:

- Total automobile person trips
- Total auto drivers who need a car to do one's work
- Total transit trips
- Total railway trips
- Total transit trips made by people with no driver's licence or no cars owned
- Average door-to-door time by auto
- Average door-to-door time by transit
- Average number of transfers by transit
- Average number of riders by auto

Lastly, for each origin or destination zone the following data was tabulated:

- Average walking time to and from transit
- Average walking time to and from auto
- Average parking cost
- Frequency of parking by: free, street meter, pay.

These data were integrated with supplementary data for calculation of the four modal split factors (See 4.1.3).

4.1.2 Data to Augment Home Interview Survey

Data on all travel excess times except walking times, on transit fares and motor vehicle operating costs had to be derived from miscellaneous sources of information.

4.1.2.1 Motor Vehicle Excess Times

Vehicle excess times at the origin of the trip (home) were assumed to be negligible and were accordingly set equal to zero. At the destination and non-home end of the trip, the following excess times were applied:

Zones	50, 61, 62, 63 65, 66 67, 69, 70, 71, 72, 73 74 (downtown and up-town zones adjacent to subway)	6 minutes
Zones	21, 85	3 minutes

4.1.2.2 Excess Time for Transit

Transit and railway wait plus transfer times were determined for each selected origin and destination interchange. As described in Section 4.1, each study zone was delineated to have uniform transit service. This meant that all routes entering or leaving a zone would provide similar service at approximately equal headways. The most direct routing of transit vehicle(s) which offered minimum headway(s) of service was determined from an investigation of published route maps. The wait and transfers times were determined for the best O-D transit (or railway) interchange by summing one-half

the scheduled headways of each route that would be most likely used in O to D travel. Peak and off-peak times were calculated from the peak and normal (off-peak) operating schedules of the T. T. C., Grey Coach, Colonial Coach, CNR and CPR Railway Companies, etc.

4.1.2.3 O-D Transit Fare

The fare was determined separately for travel via each transit company and via railway. All O-D fares were obtained from 1964 tariff schedules.

4.1.2.4 Vehicle Operating Costs

Vehicle operating costs were calculated by the solution of empirical fuel consumption formulae derived by Bevis[1] and May[2] who have shown that fuel consumption per mile of travel is a function of the travel speed. Average travel speeds for each O-D interchange were derived from grid coordinate information and travel time data. The airline distance based on grid coordinates of O and D was multiplied by a factor of 1.3 to give representative distance data for travel over a road system. Motor vehicle running time was equated to door to door time minus the excess time allowances

1. H. W. Bevis, "The Application of Benefit-Cost Ratios to an Expressway System", Highway Research Board Proceedings, Vol. 35, 1956.

2. A. D. May, Jr., "A Friction Concept of Traffic Flow". Highway Research Board Proceedings, Vol. 38, 1959.

described in section 4.1.2.1.

The cost of one Imperial gallon of fuel was taken as 40 cents in 1964 for the MTARTS Region, and oil and lubrication costs were figured at the rate of four dollars and fifty cents ($4.50) per thousand miles. Therefore, the average automobile operating cost was calculated by adding the one-way operating cost according to fuel consumption times forty cents (.40¢) per gallon and the amortized portion of the oil and lubrication costs.

4.1.3. Factors Determining Choice of Travel Mode

Four basic factors were considered as follows:

(1) Travel Time Ratio:

Relative travel time savings expressed by the ratio of door-to-door transit travel time to motor vehicle travel time.

(2) Travel Cost Ratio:

Relative travel cost savings expressed by the ratio of out-of-pocket transit travel cost to motor vehicle travel cost.

(3) Travel Service Ratio:

Relative level of service or convenience expressed by the ratio of excess travel times in travel on public transit to excess motor vehicle travel times.

(4) Economic Status:

Economic status of trip makers measured by average income per worker on an aggregate zone basis.

The procedure of deriving each of the determinant factors is described below:

4.1.3.1 Travel Time Ratio

Door-to-door travel times of transit and auto were obtained from survey data. The travel time ratio was the ratio of transit to automobile time. In the case of alternative transit and railway facilities, a weighted average was calculated depending on the trip interchange.

4.1.3.2 Travel Cost Ratio

Transit travel costs were equated to the average public transit one-way commuter fare, as described in section 4.1.2.3. Motor vehicle costs were the one-way out-of-pocket trip costs: motor vehicle operating cost (gasoline, oil, lubrication), and one-half parking cost. These costs were evenly distributed among all occupants of the motor vehicle based on the principle of cost sharing which usually exists in car pool arrangements. The travel cost ratio was transit cost divided by motor vehicle costs per person.

4.1.3.3 Travel Service Time Ratio

The convenience factor was expressed in quantitative terms as the ratio of public transit excess travel times to excess times via motor vehicle travel. Transit excess times were the sum of all waits, walks and transfers experienced in public transit trips. The source of these data has been described in section 4.1.1.3 and 4.1.2.2. Similarly the source of motor vehicle excess times is described in section 4.1.2.1. To recap, it was assumed that motor vehicle excess

times were applied at the work end of the trip but were negligible at the origin or home end.

4.1.3.4 Economic Status

The economic status of the population was measured by the average income per worker, summarized on a trip origin basis. The source of this data is described in section 4.1.1.4.

4.1.4 Methods Used in Deriving MTARTS Modal Split Relationships

The calculation of the four main determinant factors affecting travel mode choice has been described in section 4.1.3. This section describes the procedure followed in relating O-D transit usage to time ratio, after stratification of the data by the remaining factors.

Three of the four determinants were divided into a number of stratification ranges as follows:

(i) Cost ratio is divided into three ranges:

0 to 0.5
0.5 to 1.5
greater than 1.5

(ii) Service ratio is divided into three ranges:

0 to 1.5
1.5 to 3.5
3.5 and over

(iii) Economic status was divided into three ranges:

1964 Income Ranges in 1961 Toronto Dollars:

$0 to $3190

$3190 to $4840
$4840 and over

The 1964 Toronto income ranges are expressed above in equivalent 1961 Toronto constant dollars for comparison with previous analysis in Toronto and other cities.

1961 Income Ranges in 1961 Toronto Dollars:

$0 to $3100
$3100 to $4700
$4700 and over

These ranges of stratification were chosen such that each covered roughly equal variations of the factor in question. Investigation of the basic survey data has shown that these stratification levels explain adequately, differences in the ridership habits of the public. The findings did not support the derivation of diversion curves for the maximum of 80 stratifications, which were possible within the framework of the research project.

The division of the data calls for the stratification of the basic time ratio diversion curve into 27 curves. For each stratification of the data by the remaining determinants, the proportionate mode ridership is then related to travel time ratio.

Individual stratified O-D observations are not plotted immediately. A grouping procedure is carried out in an attempt to remove random scatter in the data before attempting to draw the modal split curves.

Upon grouping O-D observations which fall into time ratio

intervals differing by approximately 0.25, weights are assigned according to the total interchange volume, then the weighted average transit usage is calculated for the average point in each time ratio interval. The grouped data are then plotted on graph paper. Linear, and in a few cases curvilinear lines, are drawn as a best fit through the plotted data, which generally agree with the least squares fit to the ungrouped data.

4.1.5 Discussion of Random Variation of Data

The random variation of the data is due mainly to two factors, survey sampling error and effect of zone size. A discussion follows of each of these sources of random variation in the data.

4.1.5.1 Survey Sampling Error

The magnitude of sampling error is a function of the observed number of person interchange trips. The more people who report trips, the greater is the confidence that the sample is representative of the whole population. Consequently, survey sample size regulates the magnitude of this component of random variation. A theoretical approach to estimating this error is based on the theory of the Binomial Probability Distribution.

For the case of a 1 in 20 (5%) sample survey, Table 2 shows the dependence of one standard deviation of percentage usage on differing unexpanded trip interchange volumes (V) and different mean percentage usage (P).

Table 2

ONE STANDARD DEVIATION, σ,
FOR VARIOUS VALUES OF V AND P,
FOR A SAMPLE SIZE OF 1 IN 20 (5%)

V \ P	10%	25%	50%	75%	90%
40	21	29	35	29	21
80	14	20	24	20	14
160	10	14	17	14	10
200	9	12	15	12	9
320	8	10	12	10	8
400	7	9	11	9	7
600	6	7	9	7	6
800	5	6	8	6	5
1000	4	5	7	5	4

For example for an observed (unexpanded) volume of 1000 person trips and mean modal split of 50%,the actual modal split may be as little as 43% (50-7) or as much as 57% (50+7) with 67% confidence or reliability.

4.1.5.2 The Effect of Zone Size

To reduce data handling, trip ends are grouped into origin and destination study zones which are of considerable size in some cases. The travel time, cost and service between a pair of such districts must be average values, which describe the trips between them as well as possible. However, the average values of these determininants may differ considerably for trips starting and ending

at opposite sides of two zones. Consequently one would expect a variation in transit usage for two such cases. Similar scatter also results because the inhabitants of areas are not homogeneous as regards income, yet are assigned the same average figure.

Since several O-D pairs are grouped as having similar economic status, cost ratio and service ratio, according to the divisions described in the opening paragraph of section 4.1.4, additional variation is expected. Such variation is comparable with that of the effect of zone size.

These two sources of variation are in conflict since a reduction in zone size, to decrease averaging errors, leads to an increase in sampling errors, due to decrease in interchange volume (for same sample size). Zone size was chosen to minimize, where possible, such errors, leading to the choice of zones used in this analysis.

The actual variation of stratified data about group means was calculated for several sets of stratified groups of O-D pairs. Generally the variation in the data was less than the variation expected from the two sources.

Trip data of the Philadelphia Home Interview Survey conducted in 1960 plus other supporting technical information was available to Traffic Research Corporation for the purpose of the research. A discussion of the survey data follows:

4.2.1. Home Interview Survey Data

The survey was a source of information about how people actually travelled to Centre City, the central business district (CBD) of Philadelphia. The trips were reported for ten major transportation modes:

1.	Auto driver	6.	Streetcar or Trolley
2.	Auto passenger	7.	Taxi passenger
3.	Railroad	8.	Truck passenger
4.	Elevated Subway	9.	Walk to Work
5.	Bus	10.	School Bus

Trips involving transfers between different modes were linked and assigned the mode code of highest priority. The mode priorities were as follows:

1. Railroad
2. Elevated Subway
3. Streetcar and Subway
4. Bus
5. Auto, auto passenger

In addition to indicating mode of travel used for each trip, the survey also reported a number of factors from which modal choice determinants were calculated. Relevant trip data are out-

lined below with reference to each basic determinant.

(a) Travel Time

Departure and arrival times were reported for each trip, thus providing all the information needed for the time determinant, for both public and private automobile trips.

(b) Travel Cost

The type of parking used (i. e. free, lot paid, street metered), bridge crossings and the automobile occupancy were listed for each automobile driver trip. An average trip parking cost on destination (D) summary basis was obtained by combining rate data with the information of type of parking. Likewise average bridge tolls were based on information concerning use of bridges and the toll charges. This, however, supplies only partial information for the cost determinant since transit fare and automobile operating cost are also necessary for its calculation.

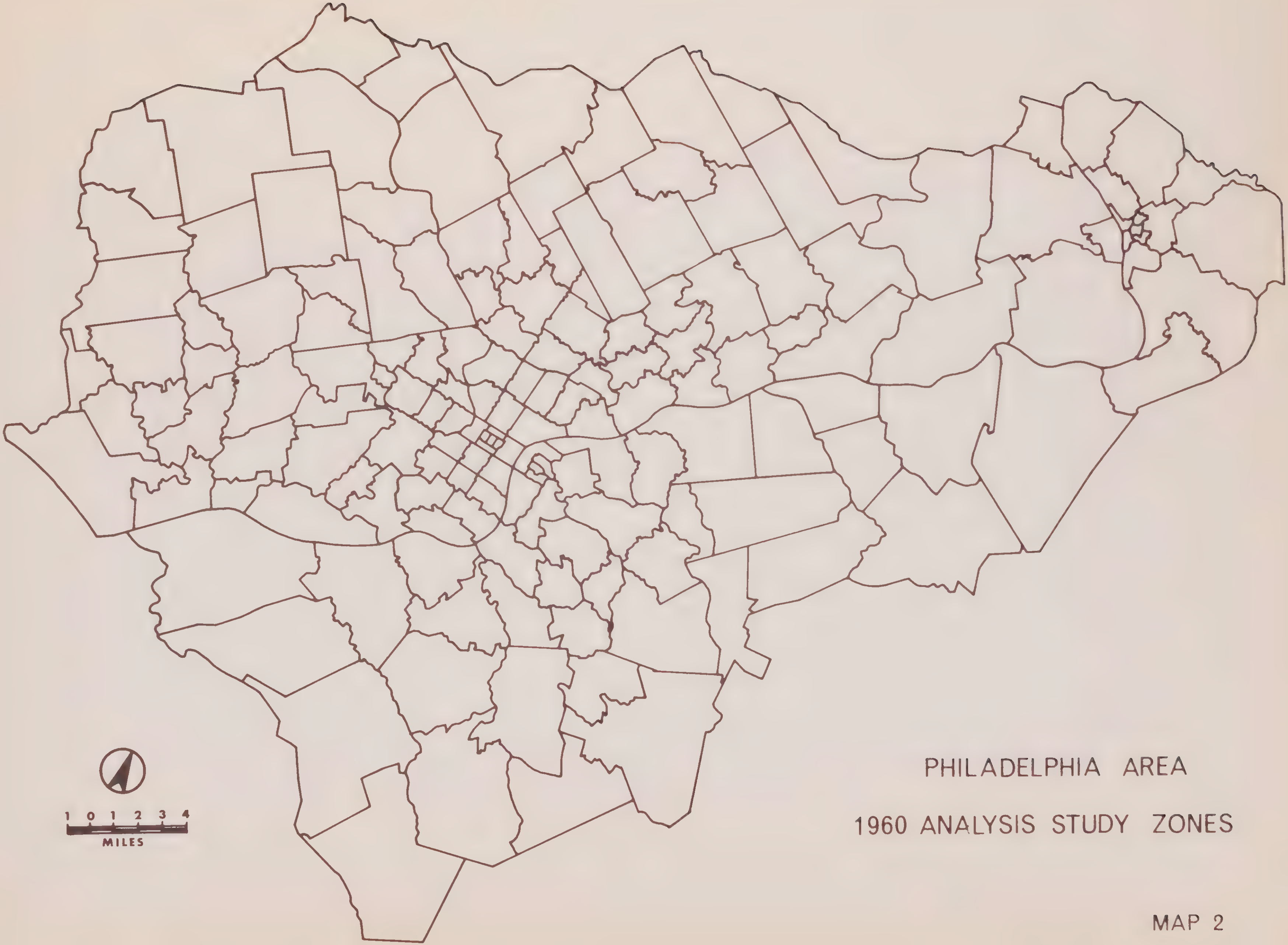
(c) Travel Convenience

No information was available from the survey.

(d) Economic Status

The total family income was reported for each household interviewed. From a summary of the data, an average figure was estimated for each O-D district. This family income data plus an accounting of the residential labour force was sufficient data for the calculation of average worker income, i. e. average income per worker being equal to family income divided by total household labour force (employed and unemployed).

Special programs were prepared for the purpose of summarizing Philadelphia data on O-D, O, or D zonal basis (See Map 2 Study Zones). This was a necessary step since the



PHILADELPHIA AREA

1960 ANALYSIS STUDY ZONES

MAP 2

format of the trip file was different from that of the MTARTS data. Following is a list of the data that were summarized and transferred to magnetic tape:

1. Origin and Destination Zones of Trip
2. Travel Time Ratio
3. Travel Time by Motor Vehicle
4. Travel Distance
5. Car Occupancy
6. Number of automobile drivers who use the following parking facilities (expanded by appropriate factor)

    (a) free
    (b) lot and garage paid
    (c) street metered

7. Number of automobile drivers who use each bridge crossing on the Delaware
8. Number of trips by all modes that are considered conveyance modes (exclude walk to work)
9. Number of elevated subway, streetcar, trolley, bus passengers
10. Number of rail passengers who use each of the following accesses to rail mode combinations:

    (a) walk to rail
    (b) auto to rail
    (c) transit to rail

11. Percent Ridership by automobile, railroad and other transit
12. Percent railroad and/or transit ridership that is captive.

These data were combined with supplementary information for calculation of the four Modal Split factors, and finally for use in deriving the Modal Split Relationships. A discussion of this next stage of data summarization is contained in the following section.

4.2.2 Data to Augment Home Interview Survey

A description follows about data on parking costs, bridge tolls, walking and other terminal times for motor vehicular travel, excess time allowance for travel via public transit facilities, and fares. This information was necessary to augment the Home Interview Survey. Although it comes from independent sources, it is generally considered applicable for this research program.

4.2.2.1 Parking Costs

Listed below in Table 3 are the calculated average parking rates for each district in the Center City area (Philadelphia CBD). The rates are based on a 1958 Parking Survey conducted for the Philadelphia Parking Authority by Wilbur Smith and Associates. The data was updated to 1960 by averaging the 1958 rates and sample off-street rates for 1962.

Table 3

PARKING RATES - 1960

Study Zone	Street Metered Rate		Off-Street Lot and Garage Rate	
	(8 Hour) ¢	(2 Hour) ¢	(8 Hour) ¢	(2 Hour) ¢
101	40	10	125	80
102	40	10	140	80
103	40	10	110	70
111	40	10	90	70
112	40	10	90	70
113	40	10	90	70
114	40	10	80	70

The Home Interview Survey data on kind of parking used for each automobile trip was summarized by Study Zone in Center City. Table 4 shows the results of this summary as percent usage of free facilities, street metered and off-street facilities by automobile drivers parking in each zone.

Table 4

PARKING USAGE - 1960
PERCENT USAGE OF FACILITIES

District	Free %		Street Metered %		Off-Street Lot & Garage %	
	Work	Non-Work	Work	Non-Work	Work	Non-Work
101	33	34	1	1	66	65
102	31	33	2	7	67	60
103	39	36	6	14	55	50
111	64	63	3	8	34	29
112	55	68	3	16	42	16
113	59	69	2	16	39	15
114	44	57	4	11	52	32

Rate and usage data were combined to provide average parking cost for a motor vehicle trip in each zone. This figure accounts for the fact that a certain amount of the parking is free, consequently, average rates are factored by the ratio of pay to total usage. The average parking costs are shown in Table 5.

Table 5

PARKING COST - 1960

District	Parking Cost ¢	
	Work Trips	Non Work Trips
101	83	52
102	95	49
103	63	36
111	32	18
112	39	13
113	35	12
114	43	24

One half of the parking costs itemized in Table 5 were used in the calculation of the one-way cost of a motor vehicle trip. This parking cost is assumed for all trips arriving in each Center City Zone, irrespective of the point of trip origination. (This data was not used in Toronto.)

4.2.2.2 Bridge Tolls

When calculating motor vehicle trip costs, a toll cost for crossing the Delaware River from districts in New Jersey was included. The toll costs per automobile for bridge crossings are shown in Table 6.

Table 6

TOLL COSTS PER AUTOMOBILE

Bridge	Toll (¢)
0 - Chester Ferry	55
1 - Walt Whitman	18
2 - Benjamin Franklin	18
3 - Turony Palmyra	5
4 - Burlington-Bristol	5
5 - NJ - PA Turnpike	40
6 - Route 1	6
7 - Route 1A	free
8 - Calhoun Street	free
9 - Yardley	free

An average toll cost per O-D motor vehicle interchange was determined by combining information of percent usage of each bridge and the toll cost. Percent usage of each bridge for New Jersey to Center City movements (crossing the Delaware) was determined from a summary of expanded Home Interview Survey data.

4.2.2.3 Motor Vehicle Excess Time

Average walking times were obtained by converting average walking distance data from a Wilbur Smith Survey, on the basis of a walking speed of 3 m.p.h. Estimates of parking delay times were generally based on knowledge of lot and garage operation. Total excess times, walking to parking and the delay at parking facilities, are shown in Table 7. These aggregate

totals were generally considered representative of the total excess time for travel by auto.

Table 7

AUTO EXCESS TIME

District	Average Excess Time (minutes) (Work & Non Work Trips)
101	9
102	12
103	9
111	6
112	6
113	6
114	6

4.2.2.4 Excess Time Allowances for Transit

The basic peak hour transit excess times used, were 4 and 6 minutes walk plus wait times as representative of approach time at trip origin, transfers or approach time at trip destination. The 4 minute allowances apply within built-up areas of Philadelphia and the 6 minute allowance in all other areas. The 4 and 6 minute allowances applied for both travel on railroads and other forms of transit. Off peak trip origin times were increased by 50 percent, but trip destination times were assumed to remain the same as peak hour. Experts on

the staff of the Penn-Jersey Transportation Study, with a good knowledge of the transit and railroad systems, considered such estimates generally representative of the actual situation.

For railroad travel, additional time allowances were made for walking, at 3 m. p. h. to or from stations or between stations and transit connections. A peak hour allowance of 4 minutes, or an off peak allowance of 12 minutes was also made at the station for climbing steps and waiting at a station which was accessible by walking or auto. A few extra allowances were made for unusually long walks to transit (not railroad).

Travel times in motor vehicles for approach to stations were not included. Such times were considered trip travel times but not excess times.

Total O-D trip excess times were determined. The data were based upon inspection of the available routes, and a selection of the most probable ones used. Separate summaries were prepared for travel on railroad, and travel on other transit.

4.2.2.5 O-D Transit Fare

The fare was reported separately for travel via railroad and travel via other forms of transit. All fares were based on 1960 rates, token or ticket rates (commutation) for transit and average commutation rates for railroads. All fares reported

covered the complete trip including transfers where payment was required. A 3¢ per mile charge for auto to railroad connections is included for the combination auto-railroad trip. In certain built-up areas where transit-railroad travel appeared to be more desirable it was surmised that some parking charges must have applied. Hence a 20¢ one-way parking cost was included for the auto-railroad fare (based on 5¢ hourly metered rates). Therefore, three fares were recorded for travel by rail, i.e. walk-railroad, transit-railroad, auto-railroad.

Separate information about fares and excess travel times was reported for each of the public transportation sub-modes: walk-railroad, transit-railroad, auto-railroad and other forms of transit. However, an average figure for public transportation was required for comparison with that of motor vehicle travel. Such average figures were derived by weighting each O-D fare by the number of sub-modal expanded users as recorded in the Home Interview Survey. Likewise, an average excess time allowance was calculated by a similar weighting process.

In the next section, there follows a description of the modal split factors and how Philadelphia data were employed in the calculation thereof.

4.2.3 Factors Determining Choice of Travel Mode

The same four basic factors were considered for the development of the Philadelphia relationships i.e.

(a) Ratio of Travel Times

(b) Ratio of Travel Costs

(c) Ratio of Excess Times

(d) Worker Income

All comments which were made in connection with determining the MTARTS Modal Split factors apply for the Philadelphia research with the following exceptions: (See Chapter 4.1.3)

(a) Cost of a gallon of fuel (American) 30¢ in 1960

(b) Cost of oil and lubrication - \$3.00 per 1000 miles in 1960

(c) Bridge tolls were included in cost of auto trip.

4.2.4 Methods Used in Deriving Philadelphia Modal Split Relationships

In accordance with the specifications of the research project, Philadelphia Modal Split Relationships were derived for the 27 basic stratifications. Identical time, cost and service ratio intervals or ranges were applied. The income ranges varied slightly, however, in order that 1960 Philadelphia income ranges might be expressed in 1961 Toronto constant dollar incomes i.e.

Philadelphia income ranges were as follows:

$\$ \quad 0$ - 2980

\$2980 - 4520

\$4520 - and over.

5. RESULTS OF THREE-WAY MODAL SPLIT RESEARCH

The findings of the Modal Split Research are presented below. The results are presented in tabular and graphical form. An interpretation of the findings is given where possible.

5.1 Impact of Captive Ridership on Automobile and Transit Usage

A transit or railway rider is designated as captive if one or more of the following travel or household characteristics is applicable:

(a) traveller does not have a driver's licence

(b) traveller is under 16 years of age

(c) household does not own a car

The percent captive transit ridership for both work and non-work travel was summarized for the MTARTS and Philadelphia Regions. The findings are presented in Tables 8 and 9 for MTARTS and Philadelphia respectively.

The captive ridership for work travel in peak periods is significantly lower than that for non-work travel in off peak periods. This is expected since off peak travel by transit is recognized as being less convenient than peak travel (longer headways for transit operation). Accordingly, transit riders are more apt to be captive. while a greater proportion of non-captive riders choose to ride by automobile. There appears to be slight differences in the captive work ridership between travel to downtown. adjacent to downtown and uptown study zones. The

differences are probably explainable by the differences between zones in availability of free parking and level of convenient transit service.

Table 8

CAPTIVE TRANSIT AND RAILWAY RIDERSHIP
IN MTARTS REGION

DESTINATION ZONE	PERCENT CAPTIVE RIDERSHIP Work	Non-Work
50	59%	76%
61	50%	73%
62	61%	88%
63	59%	72%
Average for zones in Eglinton, Yonge Area	58%	75%
65	60%	77%
66	64%	93%
67	47%	82%
69	77%	100%
71	78%	96%
74	50%	91%
Average for zones adjacent to Downtown	61%	85%
70	48%	70%
72	61%	81%
73	53%	75%
Average for zones in Downtown Area	53%	78%
21	58%	49%
85	64%	100%
Average for All zones	56%	78%

Table 9

CAPTIVE RIDERSHIP ON TRANSIT AND/OR RAILROAD IN PHILADELPHIA

(summary to all downtown destination zones)

MODE	% CAPTIVE RIDERSHIP	
	WORK	NON-WORK
RAILROAD	14 %	55 %
TRANSIT	57 %	80 %
TOTAL	49 %	78 %

The captive ridership on transit is noticeably higher than that on railway. The difference is particularly large for work travel in peak periods. The difference is explainable when you recognize the following facts:

(a) Railway serves low, middle and high income areas;

(b) In low and middle income areas served, the railway fare is two and one-half times the transit fare (50¢ versus 20¢);

(c) In high income areas served, the railway fare is equal to or slightly greater than the transit fare (70¢ versus 40¢ to 70¢).

It is apparent that in low income areas, the captive public transportation riders are using transit in preference to rail. In the high income areas, where every household owns at least one car, the overall percentage captive ridership is small.

For non-work travel, the captive ridership in the MTARTS and Philadelphia Regions are equal. However, for work travel, there is a

small difference with a higher captive value in the MTARTS Region. It is interesting to note, however, that the transit captive rate equals that of MTARTS. It is recognized that almost all travel in MTARTS Region is by transit and therefore only the transit rates may be comparable.

An automobile driver was classified as captive if he or she answered the question "car necessary to do work" in the affirmative as a reason for using the car (i. e. question A. 1 on form 4 was answered very important or important). The percent captive automobile ridership was determined from all survey questionnaires. This percentage is shown only for car driver trips made to work. The findings are presented in Table 10 for the MTARTS Region. Similar information on captive automobile drivers in Philadelphia was not obtained in that survey, and hence was not available for comparison with the MTARTS facts. An overall captive driver percentage of 38 was observed. This figure is less than the percentage of captive transit work trips reported for the MTARTS Region, i. e. 56 percent. It is noteable that the captive driver rate is as high as shown, and is not that much less than the captive transit figure. The captive automobile rate appears to vary slightly according to trip destination. The lowest rate is shown for the zones adjacent to downtown. There is no apparent explanation for the low captive rate for study zone 61.

Table 10

CAPTIVE AUTOMOBILE DRIVER RIDERSHIP
IN MTARTS REGION

DESTINATION ZONE	PERCENT CAPTIVE RIDERSHIP Work
50	46%
61	19%
62	49%
63	42%
Average for zones in Eglinton, Yonge Area	41%
65	29%
66	37%
67	35%
69	33%
71	44%
74	31%
Average for zones adjacent to Downtown	35%
70	43%
72	37%
73	45%
Average for zones in Downtown Area	42%
21	25%
85	30%
Average for All zones	38%

5.2 Definition of Data Stratifications for Derivation of Modal Split Relationships

The data stratifications chosen for the derivation of the Modal Split diversion curves were the following:

(a) Three levels of Worker Income:

EC	(1)	$0 to $3190
	(2)	$3190 to $4840
	(3)	$4840 and over

(b) Three levels of Cost Ratio

CR	(1)	0.0 to 0.5
	(2)	0.5 to 1.5
	(3)	1.5 and over

(c) Three levels of Service Ratio:

SR	(1)	0.0 to 1.5
	(2)	1.5 to 3.5
	(3)	3.5 and over

Investigation of the basic survey data has shown that these stratificiation levels explain adequately differences in the ridership habits of the public. The findings did not support the derivation of diversion curves for the 80 stratifications which were suggested by the Submission II.

The 80 stratifications attempted originally for work and non-work travel were as follows:

(d) Five levels of Worker Income:

(1)	$0 to $3190
(2)	$3190 to $4840
(3)	$4840 to $6380
(4)	$6380 to $7720
(5)	$7720 and over

(e) Four levels of Cost Ratio:

(1) 0. 0 to 0. 5
(2) 0. 5 to 1. 0
(3) 1. 0 to 1. 5
(4) 1. 5 and over

(f) Four levels of Service Ratio:

(1) 0. 0 to 1. 5
(2) 1. 5 to 3. 5
(3) 3. 5 to 5. 5
(4) 5. 5 and over

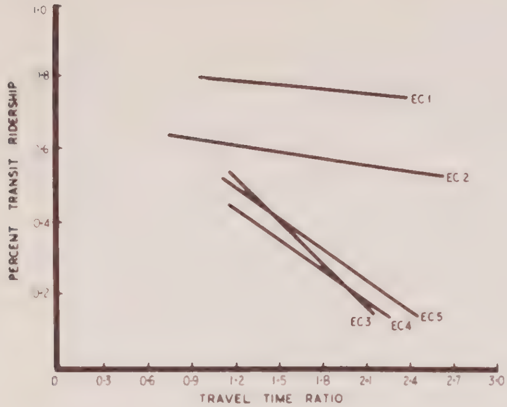
Empirical tests conducted with the above 80 stratifications are demonstrated by Figures 4 and 5 for Work and Non-Work travel respectively. The basic transit usage versus travel time ratio relationships are plotted from MTARTS data in these figures in accordance with separate stratification by the five levels of worker income, four levels of cost ratio and four levels of service ratio. Investigation of these plots demonstrates the following findings:

(a) The transit usage versus travel time relationships for income stratas (3), (4) and (5) are almost identical for work and non-work travel.

(b) The basic relationships for cost ratio stratas (2) and (3) are identical for work travel and similar for non-work travel.

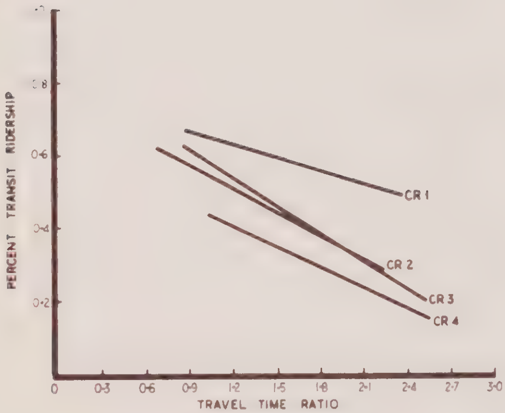
(c) Basic relationships for service ratio stratas (3) and (4) are similar for work and non-work travel. The differences are within expected sampling and aggregation errors (see Chapter 4. 1. 5) and are, therefore, considered insignificant.

TESTS WITH 80 MODAL SPLIT DATA STRATIFICATIONS BASED ON REPORTED WORK TRAVEL IN MTARTS REGION



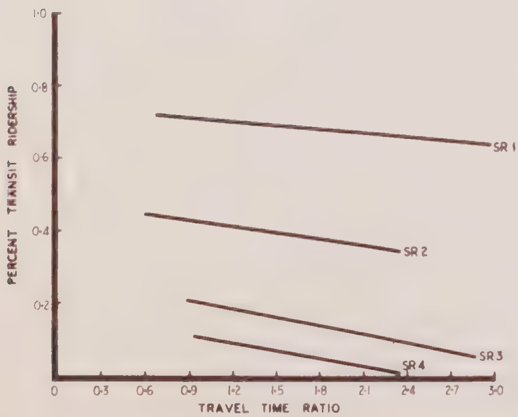
INCOME STRATA

EC - 1	$0 - $3190
2	$3190 - $4840
3	$4840 - $6380
4	$6380 - $7720
5	$7720 - AND OVER



COST RATIO STRATA

CR 1	0·0 - 0·5
2	0·5 - 1·0
3	1·0 - 1·5
4	1·5 - AND OVER



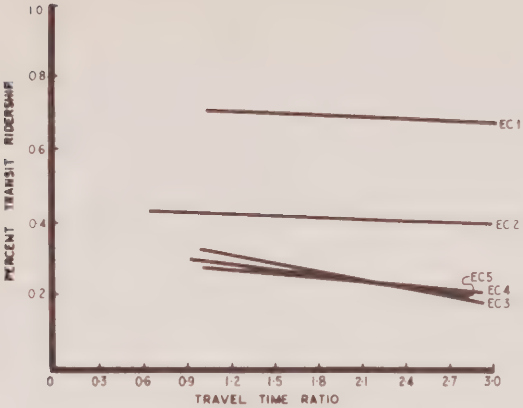
SERVICE RATIO STRATA

SR 1	0·0 - 1·5
2	1·5 - 3·5
3	3·5 - 5·5
4	5·5 - AND OVER

FIG. 4

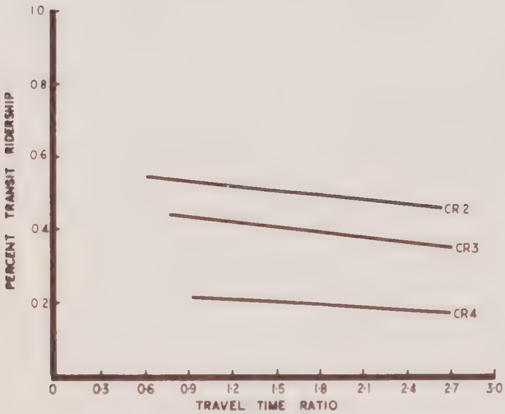
TESTS WITH 80 MODAL SPLIT DATA STRATIFICATIONS

BASED ON REPORTED NON-WORK TRAVEL IN MTARTS REGION



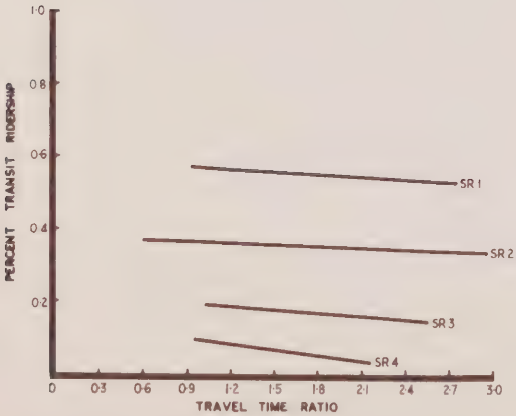
INCOME STRATA

EC-1 $0 - $3190
2 $3190 - $4840
3 $4840 - $6380
4 $6380 - $7720
5 $7720 - AND OVER



COST RATIO STRATA

CR 1 0·0 - 0·5
2 0·5 - 1·0
3 1·0 - 1·5
4 1·5 - AND OVER



SERVICE RATIO STRATA

SR 1 0·0 - 1·5
2 1·5 - 3·5
3 3·5 - 5·5
4 5·5 - AND OVER

FIG. 5

In summary, the 80 possible data stratifications were combined to form the 27 stratifications described at the beginning of this section. All stratified Modal Split Relationships were determined according to these revised 27 stratifications.

5.3 Development of Modal Split Relationships for MTARTS and Philadelphia Regions and their Comparative Evaluations

Modal Split Relationships were developed from the survey information of the MTARTS and Philadelphia Regions. These relationships described the correlation between percent combined transit and railroad ridership and the public transportation to auto travel time ratio, for each of the 27 separate data stratifications (see Chapters 4.1.4 and 4.2.4). The relationships were derived separately for work travel in the AM peak period and non-work travel during off peak periods.

Figures 6 and 7 demonstrate the relationships for work and non-work travel respectively in the MTARTS and Philadelphia Regions. The relationships for travel in each Region are shown in the same graph for comparative purposes.

The following observations are made from a study of the relationships:

COMPARISON OF COMBINED TRANSIT AND RAILROAD MODAL SPLIT RELATIONSHIPS FOR WORK TRAVEL IN MTARTS AND PHILADELPHIA REGIONS

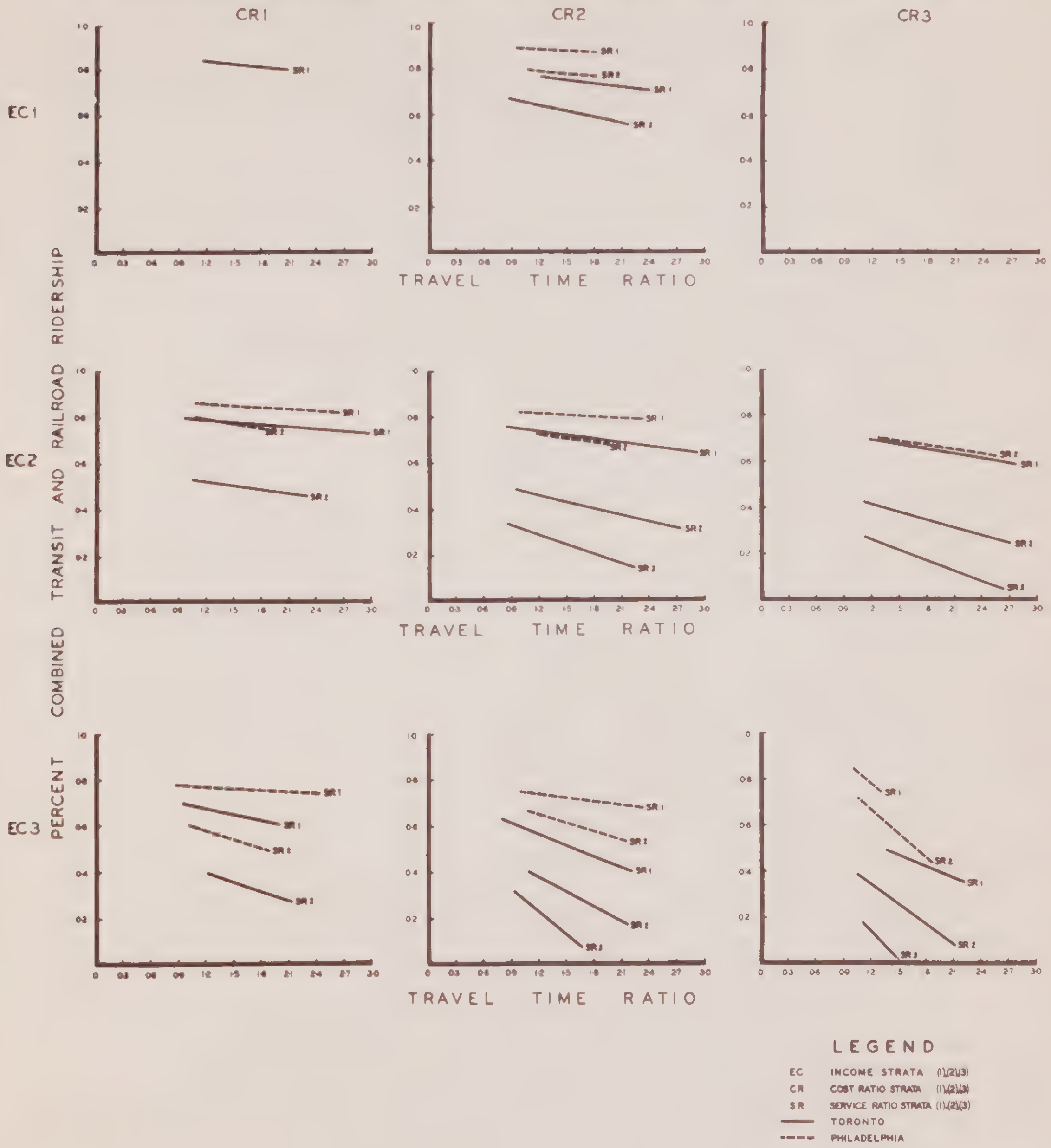


FIG. 6

COMPARISON OF COMBINED TRANSIT AND RAILROAD MODAL SPLIT RELATIONSHIPS FOR NON-WORK TRAVEL IN MTARTS AND PHILADELPHIA REGIONS

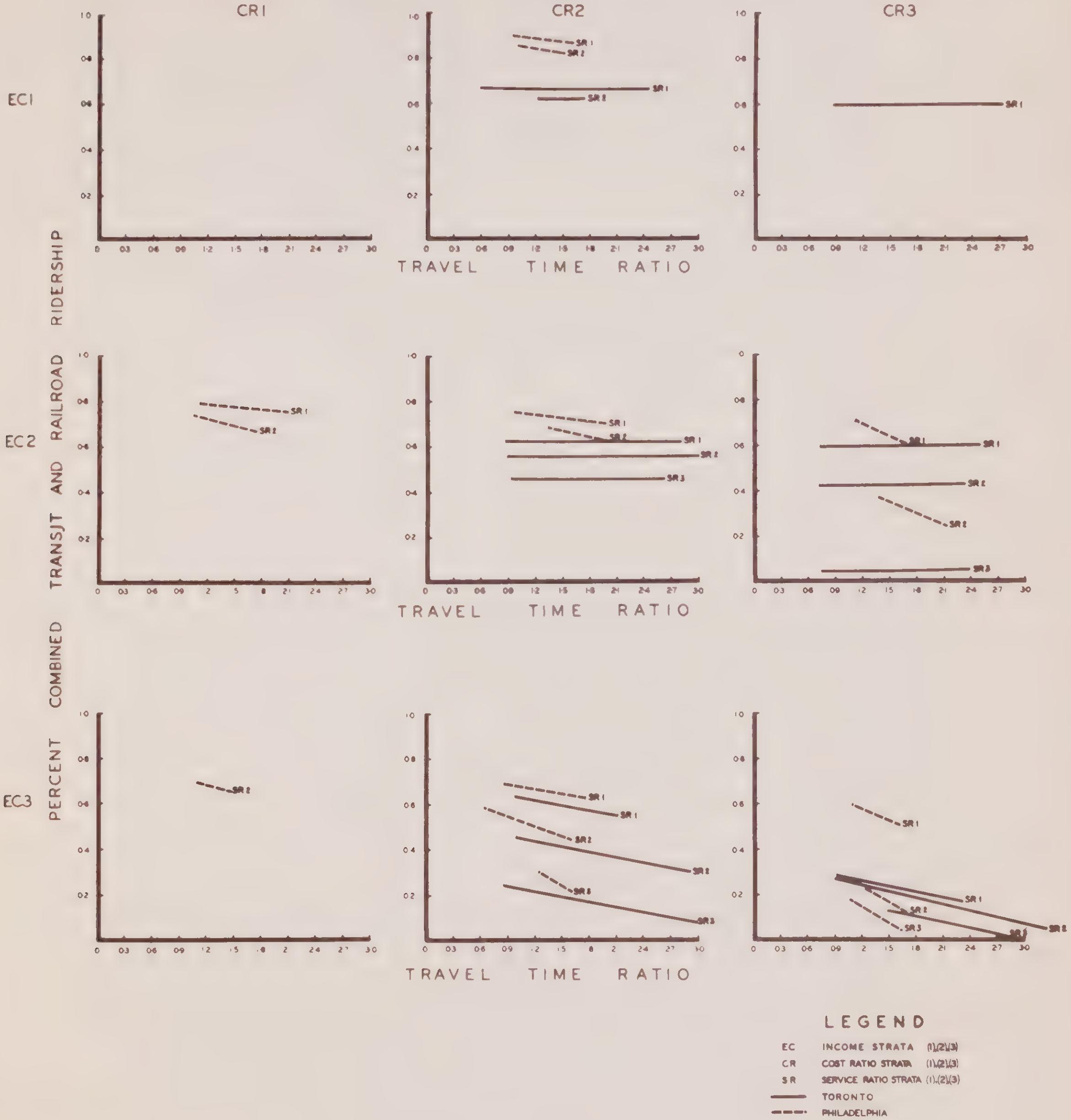


FIG. 7

(a) The percent transit and railroad ridership varies with the travel time ratio. This basic relationship appears to change according to the level of data stratification. For increasing economic status, the degree of the relationship increases (i. e. ridership becomes more elastic to changes in travel time ratio). Further, the basic relationship changes according to the cost and service strata.

(b) Observation (a) applies for both the data from the MTARTS and Philadelphia Regions.

(c) Work and non-work relationships appear to demonstrate similar trends.

A comparison of the MTARTS and Philadelphia basic Modal Split relationships for equal data strata discloses the following findings:

- Transit and Railroad Ridership is consistently higher in the Philadelphia Region, than Ridership in the MTARTS Region. The differences are consistent across all data strata for work travel, and appear to increase for the higher income, cost and service levels. The differences are less noticeable for non-work travel and appear to occur in most instances, but not all.

Any differences between MTARTS and Philadelphia Relationships greater than 20 percent ridership, generally exceeds expected survey sampling and aggregation error, and consequently are considered significant. (See Chapter 4. 1. 5) The reasons for these differences are not apparent. The fact that the captive levels of transit and railroad ridership are similar for the two regions further emphasizes the significance of the differences.

A number of conjectures for these differences are presented but are not substantiated by supporting facts.

(a) Philadelphia public transportation services operate at lower load factors (ratio of standees to seated passengers) than the services in the MTARTS Region.

(b) There is a greater acceptance of public transportation by the public in Philadelphia, than in the MTARTS Region.

(c) Inclement weather in MTARTS Region reduces overall ridership of public transportation facilities.

(d) There are more extensive rail-rapid, elevated streetcar and rail-commuter facilities in Philadelphia. Due to the superior type of service, a higher ridership in Philadelphia is realized.

It is noteworthy that the four conjectured reasons are not accounted for by the present data stratification of income, cost and service ratio. Accordingly, if any of the above reasons are valid, they could explain the difference in ridership.

5.4 Development of Separate Railroad and Transit Modal Split Relationships and their Comparative Evaluation

Separate summaries of railroad and transit ridership data were prepared and combined with summaries of private vehicle ridership. Accordingly, Separate Railroad and Transit Modal Split relationships were developed (railroad ridership is expressed as the percentage of total railroad and private vehicle trips, while transit ridership is expressed as the percentage of total transit and private vehicle trips). The relationships

were developed for each of the possible 27 data stratifications (see Chapter 4.1.4 and 4.2.4) from the available data of both the MTARTS and Philadelphia Regions.

Figures 8 and 9 show the comparative relationships for railroad and transit ridership in the MTARTS and Philadelphia Regions respectively. Close scrutiny of the comparative ridership relationships for Philadelphia discloses the following:

(a) There is no railroad ridership among the low income workers (strata (1))

(b) There are significant differences between railroad and transit ridership by middle income workers (strata (2))

(c) There are small differences between railroad and transit ridership by high income workers (strata (3)). The differences are approximately 10 percent in absolute ridership and are considered insignificant.

Railroad and transit ridership in MTARTS Region is similar and the differences could be considered insignificant. Railroad ridership figures for the MTARTS region are based on approximately 50 reported trips (expands to 1500) and are not particularly statistically reliable.

The observations (b) and (c) are not surprising when we recall the facts about captive ridership reported in Chapter 5.1. To recap, the captive ridership on railroad is only 14

percent, while it is approximately 57 percent of transit ridership. Further, it is noted that low and middle income workers have the choice between cheap transit or expensive railroad service. High income workers can choose between transit and railroad at equivalent tariffs.

The differences in captive ridership rates can easily account for a spread between railroad and transit ridership from 20 to 50 percent in absolute ridership. In summary, these observations more than account for the apparent differences of ridership for middle income workers and moderate to small differences for high income workers.

Because this particular phenomenon occurs in Philadelphia, there is no assurance that such differences between railroad and transit ridership would occur in the MTARTS Region. If large differences in railroad and transit tariffs were implemented in MTARTS Region then this phenomenon might also occur here.

On the basis of the observations for Philadelphia, it is not advisable to apply these findings (observation (b) directly in the MTARTS Region. It is concluded on the basis of observation (c) above, that if the tariffs charged for railroad and transit service are equivalent, the rates of captive ridership will be similar and therefore the ridership on railroad and transit will be approximately the same (for equal relationship

COMPARISON BETWEEN PERCENT RAILROAD RIDERSHIP AND PERCENT TRANSIT RIDERSHIP FOR WORK TRAVEL IN MTARTS REGION

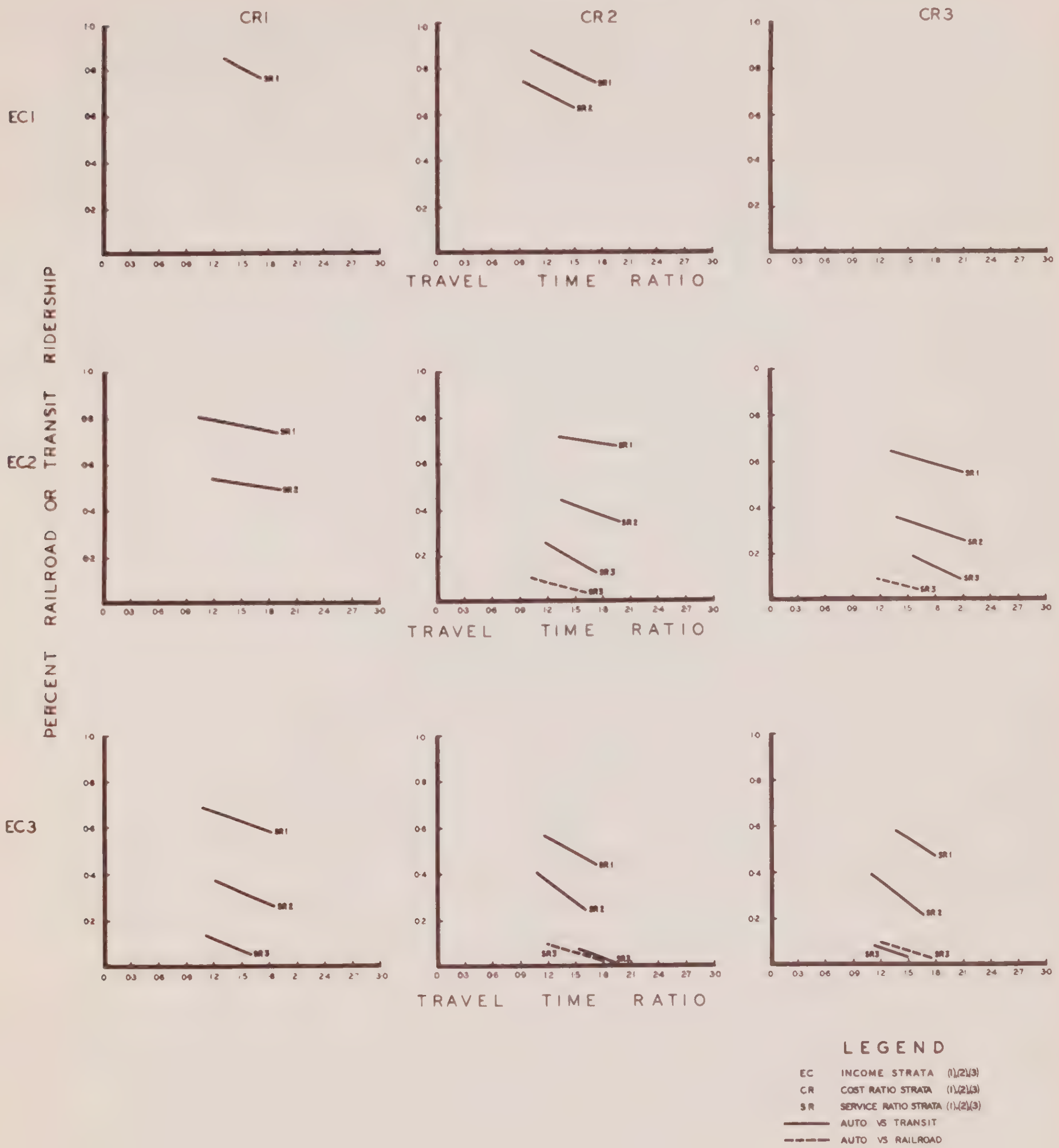


FIG. 8

COMPARISON BETWEEN PERCENT RAILROAD RIDERSHIP AND PERCENT TRANSIT RIDERSHIP FOR WORK TRAVEL IN PHILADELPHIA REGION

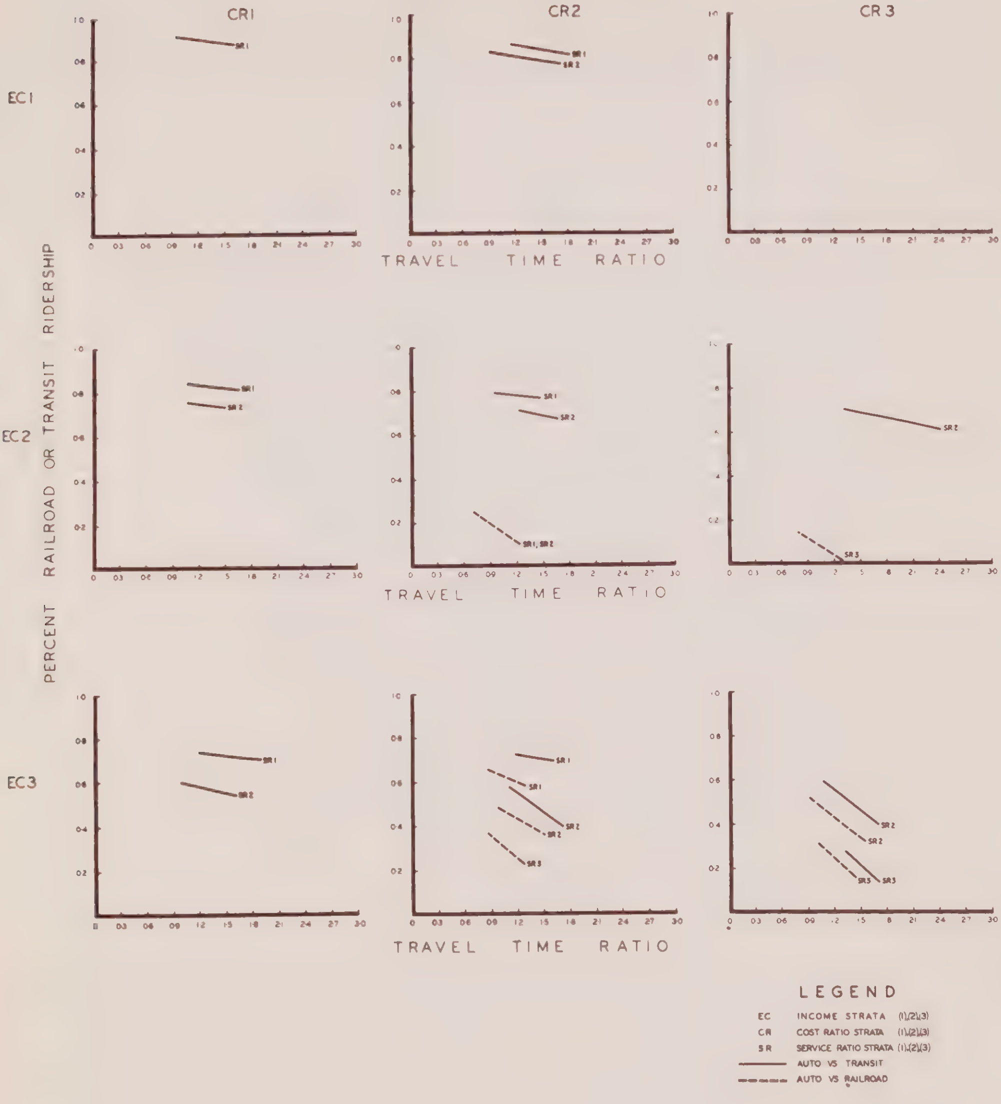


FIG. 9

strata).

It is recommended that the existing Modal Split Relationships for the MTARTS Region be applied to estimate combined railroad and transit ridership, provided of course, the tariffs are equivalent. This combined estimate can then be split into separate railroad and transit ridership in accordance with the procedure outlined in Chapter 2. 5 (see analysis in Chapter 5. 5).

5. 5 Development of Railroad versus Transit Ridership Diversion Curves

To obtain the best values of the parameters, "a" and "b", a non-linear and step-wise regression procedure was applied. (See Chapter 2. 5) The description of this procedure was prepared and is available for perusal in the TRC technical files. (see memorandum on Program YSPLIT)

The values of the parameters, "a" and "b", providing the best fit of the basic relationship to survey data are as follows:

$$\left.\begin{aligned} a &= 3.0 \\ b &= -2.4 \end{aligned}\right\} \quad \text{Set (1)}$$

These values of the parameters imply that three times the importance is attributed to cost as is attributed to time. In other words, it would appear that an hour of travel is worth approximately 33 cents.

Because it is unrealistic to attach a value of 33 cents to

an hour of travel, it was decided to use the hourly wage of eighty cents (80¢). Therefore, the following parameter values should be applied. (See Figure 3)

$$a = 1.25 \qquad b = -3.4 \qquad \text{Set (2)}$$

Note: For Set (1) and (2) time is expressed in hours and cost in dollars.

It is noteworthy, that for Set (2) of parameter values, the error of fit, which is associated with the explanation of the survey summaries by the diversion curve relationship, increases by approximately 5 percent. In view of this slight increase in the regression error, this decision appeared justified. Accordingly, we propose that the Set (2) of parameter values for "a" and "b" be applied in the Traffic Prediction Model.

In particular, the Traffic Prediction Model incorporates different measurements of time and cost. Time is expressed in minutes and cost in cents. To comply with these measurements, the following parameter values should be used.

$$a = 1.25 \times 6/10 = 0.75 \qquad b = -3.4 \qquad \text{Set (3)}$$

Further, it is recommended that the same values (3) be applied for the transit, railway and mixed mode ridership.

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